Appendix F

Evaluation of Shear Stress and Need for Over-Excavation for SED 9

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As discussed in the main text of this Revised CMS Report, alternative SED 9, as defined by EPA, differs from the other sediment remediation alternatives in a number of ways. Two of them are as follows:

1. The spatial delineation of SED 9 remediation areas in the Reach 7 impoundments (i.e., Reaches 7B, 7C, 7E, and 7G) and Reach 8 (Rising Pond) was required to be based on the bottom shear stress within those reaches (as opposed to defining remediation areas based on a single technology over an entire reach or based on depth and/or PCB concentration, as has been done for the other alternatives). For these reaches, EPA specified the following approach:

   - In areas having lower shear stress, sediments would be removed to a depth of 1 foot followed by placement of a cap back to grade. The cap in these lower shear stress areas would consist of a 6-inch active layer (assumed to consist of material containing a sorptive amendment) overlain by a 6-inch habitat/bioturbation layer (assumed to consist of sand or gravel material).

   - In areas with higher shear stress, sediments would be removed to a depth of 1.5 feet followed by placement of a cap back to grade. The cap in higher shear stress areas would be the same as that in lower shear stress areas except that it would also include a 6-inch armor layer (designed to resist erosion) at the surface.

2. EPA specified a different sequencing of construction activities for SED 9 than for the other sediment alternatives. Specifically, EPA specified that, under SED 9, sediment removal in the Reach 5 backwaters and in Reaches 6, 7, and 8 would be performed concurrently with removal activities in the Reach 5 channel (i.e., Reaches 5A, 5B, and 5C), and that placement of the caps in these backwaters and downstream reaches would be delayed until after all the removal and capping activities in the Reach 5 channel have been completed. Under this approach, the sediments exposed by removal in the reaches where the capping would be delayed would be “uncovered” for some period of time after sediment removal is complete. As a result of this sequencing, EPA directed GE to evaluate the need for additional removal, in terms of an increased removal depth, to account for any sedimentation that would occur during the period between completion of removal and initiation of capping in the subject reaches.

This Appendix describes model-based analyses that were developed to address these two aspects of the development of SED 9. Specifically, these analyses were developed to:

- Evaluate the distribution of bed shear stress and delineate regions of high and low shear stress within the Reach 7 impoundments and Reach 8; and

- Estimate the thickness of deposition that could occur during the "uncovered" periods (i.e., the time between completion of removal activities and initiation of capping activities) in the reaches where capping would be delayed, and determine what additional removal depth, if any, would be needed to account for that deposition.

The results of these analyses are presented in the following sections.

F.1 DELINEATION OF HIGH AND LOW SHEAR STRESS AREAS

Delineation of high and low shear stress areas in the Reach 7 impoundments and Reach 8 under SED 9 was based on the premise that areas subject to relatively higher shear stress would require a cap that includes an armor layer because the shear stress in these areas would be sufficiently high, such that a habitat layer nominally consisting of sand or gravel would be eroded during conditions of elevated current velocity. In general, erosion of sediment depends on both shear stress in the river bed, which is related to flow conditions, and the critical shear stress of the bed materials (e.g., particle size). As river flow increases, the river bed shear stress increases, and once that shear stress exceeds the critical shear stress for the bed material, resuspension is expected to occur. Therefore, for the purposes of this modeling analysis, "low shear stress" conditions were defined as those in which the bed shear stress is less than the critical shear stress of a sediment cap's habitat layer such that the material would be largely stable. The modeling approach used to identify the portions of the Reach 7 impoundments and Reach 8 that meet this low shear stress condition was as follows:

- The assessment was conservatively focused on the extreme flow event used in Year 26 of the CMS model projection period. The peak flow rate from this event corresponds to the largest flood on record for the Housatonic River, and is the largest simulated flow used in all CMS-related modeling (see Section 3.2.2.1 of the main body of this report).

- Since a gravel or sand habitat layer would likely be used in areas with low shear stress (as discussed above), a range of critical shear stresses associated with such material was developed from the literature (van Rijn, 1993). Based on the values in Table F-1, a conservative value of 1.9 Pascal (Pa), which is the critical shear stress for coarse sand, was selected for this analysis.

Table F-1 – Summary of Critical Shear Stress Associated with Different Size Classes of Solids (van Rijn, 1993).

Description	D 50 (mm)	Critical Shear Stress (Pa)
Medium Sand	0.5	0.5
Coarse Sand	1	1.9
Very Coarse Sand	2	4.9
Gravel	4	11

- An area was considered to have high shear stress if the bed shear stress predicted by EPA's Downstream Model exceeded the 1.9 Pa threshold value for a sustained period of time (defined as > 12 hours for this analysis) during the extreme event. Otherwise, the area was considered to have low shear stress since either the threshold value was never met or it was only exceeded for a short period of time (< 12 hours). The 12-hour criterion was used in this definition to avoid delineating areas that exceed the threshold shear stress for only a short period of time and hence would not experience substantial erosion as compared to areas where the threshold value is exceeded during a significant portion of the extreme event.

Figures F-1a through F-1e show the spatial distribution of model-calculated bed shear stress in the Reach 7 impoundments and Reach 8, as well as the changes in bed shear stress associated with river flow rate over the course of the extreme event (a time period of 5 days). It can be seen from these plots that the magnitude of model-calculated bed shear stress, as well as the spatial extent of high bed shear stress (e.g., grid cells with about 2 Pa and above), increases with increasing flow. Figure F-2 shows the frequency at which model grid cells exceeded 1.9 Pa during the extreme event. As expected, the narrow portions of the impoundments, such as the entry channels, had a greater frequency of high shear stress than the wider portions of the impoundments, where the river also generally becomes deeper. Generally, a grid cell that exceeded 1.9 Pa for greater than 12 hours (0.5 day) was defined as a high shear stress area. The following portions of the Reach 7 and 8 impoundments were identified as having high or low shear stress based on the approach described above:

- Reach 7B (Columbia Mill Dam Impoundment): The entry channel and area just above the dam were defined as having high shear stress, while the middle deeper portion of the impoundment was defined as a low shear stress area.

- Reach 7C (Former Lee/Eagle Mill Impoundment): The entire reach was defined as a high shear stress area.

- Reach 7E (Willow Mill Dam Impoundment): The entire reach was defined as a high shear stress area.

- Reach 7G (Glendale Dam Impoundment): The upper portion of this reach was defined as having high shear stress, while the deeper portion over the lower half of this reach leading up to and immediately adjacent to the dam was defined as a low shear stress area.

- Reach 8 (Rising Pond): The majority of Rising Pond was defined as a low shear stress area, with the exception of the narrow entry channel of the impoundment.

Based on the model predictions at the grid cell level described above, contiguous areas within each impoundment were delineated as having high or low shear stress, as shown in Figure F-3. This analysis resulted in approximately 34 acres of these impoundments being defined as having high shear stress, and 45 acres being defined as having low shear stress. This delineation would be revisited in design (if SED 9 were selected), particularly since a habitat layer could likely be sized to withstand the selected critical shear stress (1.9 Pa), as well as potentially higher shear stresses. However, it should be noted that the identification of high and low shear stress areas shown in Figure F-3 is generally consistent with two other observations:

- Review of the available surface sediment grain size data collected by EPA indicates that relatively coarser sediments are located in the areas of predicted higher bed shear stress (such as the narrow entry cannel to Reach 7B), and that relatively finer grain size sediment were found in the deeper slower moving portions of the impoundments. It is reasonable to expect that the present grain size distribution at the sediment surface reflects an equilibration condition with the bed shear stress.

- Based on the analyses conducted in the original CMS to evaluate the level of erosion experienced by thin-layer caps, it was found that the limited areas where erosion of thin-layer caps was predicted within the Reach 7 impoundments and Reach 8 generally matched the areas delineated as high shear stress areas in this analysis.

The results of the model simulation of SED 9 confirmed that the areas delineated as having low shear stress (based on the approach described above) are not predicted to experience significant erosion. For example, within the low shear stress areas, only a limited number of model grid cells (5 of the 16 grid cells in Reach 7B, 2 of the 18 grid cells in Reach 7G, and 2 of the 73 grid cells in Rising Pond) are predicted to experience complete erosion of the upper six inches of the cap (which corresponds to the habitat/bioturbation layer as specified by EPA).

F.2 ESTIMATION OF SEDIMENTATION DURING “UNCOVERED” PERIODS

As discussed above, the construction sequencing specified by EPA for SED 9 would result in a time delay between the completion of sediment removal and the placement of the caps in the Reach 5 backwaters, Reach 6 (Woods Pond), Reach 7 impoundments, and Reach 8 (Rising Pond). During this “uncovered” period, deposition of solids would occur. In this situation, EPA stated that GE should evaluate the increase in removal depths (over-dredging) in those areas that would be necessary to offset the sediment deposition that would occur during the “uncovered” period.

To evaluate this issue, a modeling analysis was performed to estimate the depth of sediment accumulation in these areas during this period, based on the annual deposition rate (predicted by EPA’s model) and the duration of the “uncovered” period under the construction timeline developed for SED 9. The remediation schedule developed by GE for SED 9 was presented in Figure 6-25 in the main body of this report and is repeated as Figure F-4 in this Appendix. That schedule indicates that the backwater remediation, including placement of cap material, would be completed at the same time as the remediation in Reach 5C. Since the backwater remediation would be completed concurrently with remediation in the Reach 5 channel (with no increase in the overall time to complete Reach 5), there would be no time delay between the completion of sediment removal and the placement of the caps in the Reach 5 backwaters. Therefore, there was no need to include the Reach 5 backwaters in this analysis. For the impoundments (i.e., Woods Pond, the Reach 7 impoundments, and Rising Pond), this analysis was conducted as follows:

- Based on the assumed sequencing of work under the remediation schedule developed for SED 9 (see Figure F-4), the number of years in which each reach would be “uncovered” between dredging and capping is between 3 and 4 years for these impoundments.

- Based on yearly changes in bed elevation computed by EPA’s model under the no-action alternative (SED 1), reach-averaged annual deposition rates were calculated over the 52-year model projection period in each of the subject reaches. Rolling averages of annual deposition rates for each reach were then calculated based on the duration of each reach's "uncovered period". Since the annual deposition rate is affected by the flow conditions for a given year, the rolling-average approach considered a combination of flow conditions in the future. This approach is more conservative than using a long-term average deposition rate and more realistic than using the maximum deposition rate.

- Based on these durations and rolling averages of annual deposition rates derived above, the total thickness of deposited sediment in a given reach was estimated based on the time it would be uncovered and the maximum rolling average deposition rate predicted by the model for that reach.

The resulting thickness of sediment accumulation by reach is presented in Table F-2 below.

Table F-2 – Total Deposition by Reach during the Uncovered Period

Reach	"Uncovered" Duration (years)	Deposition Rate (cm/yr)[1]	Total Deposition (inches)
Reach 6	3.3	0.5	0.8
Reach 7B	3.7	0.2	0.4
Reach 7C	3.7	0.02	0.1
Reach 7E	3.7	0.2	0.3
Reach 7G	3.7	1.0	1.5
Reach 8	3.9	0.2	0.3

[1] Maximum 3-year (Reach 6) or 4-year (Reaches 7-8) rolling average from the 52-year model simulation of SED 1.

The model-predicted thicknesses of sediment deposited in these areas during the 3- to 4-year uncovered periods under SED 9 are small. Total estimated deposition in five of these six impoundments is less than one inch, and the estimated deposition in the remaining impoundment (the Glendale Dam Impoundment) is approximately 1.5 inches (Table F-2). These thicknesses are within the anticipated accuracy and allowable dredge depth tolerances for current environmental dredging equipment. Moreover, it is likely that the accumulated sediments would consolidate once the relatively dense capping material (typically sand and gravel, or large sized materials in the case of armor stone) is placed on the river bottom. This would further offset any additional accumulation of sediments during the uncovered period.

This analysis indicates that it is not necessary to increase the base removal depths in these areas under SED 9 to account for deposition of sediment between the time removal is completed and the time capping begins.

References

van Rijn, L.C. 1993. *Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas,* Aqua Publications.

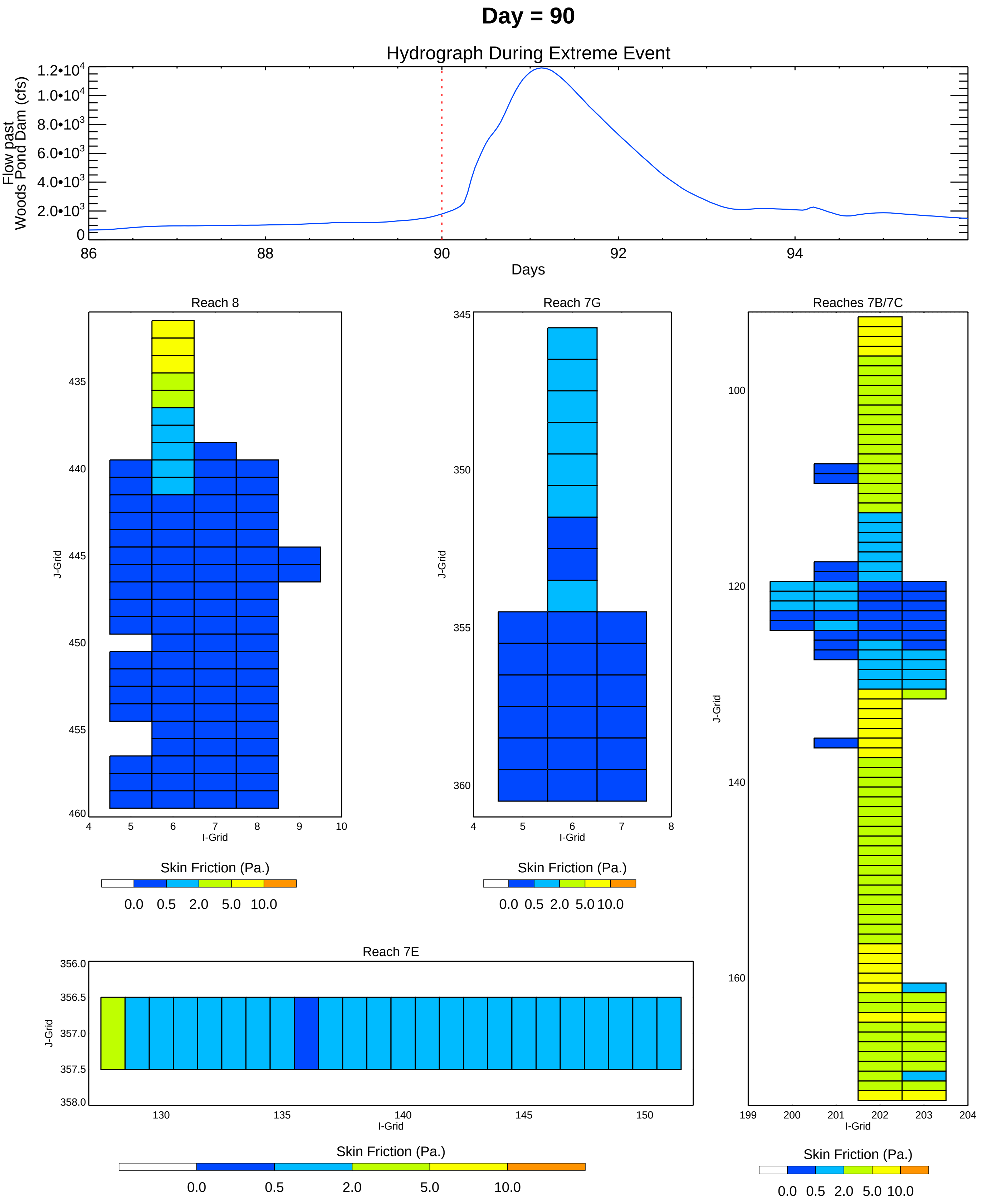

Figure F-1a. Model Calculated Skin Friction During the Extreme Event (Day 90)

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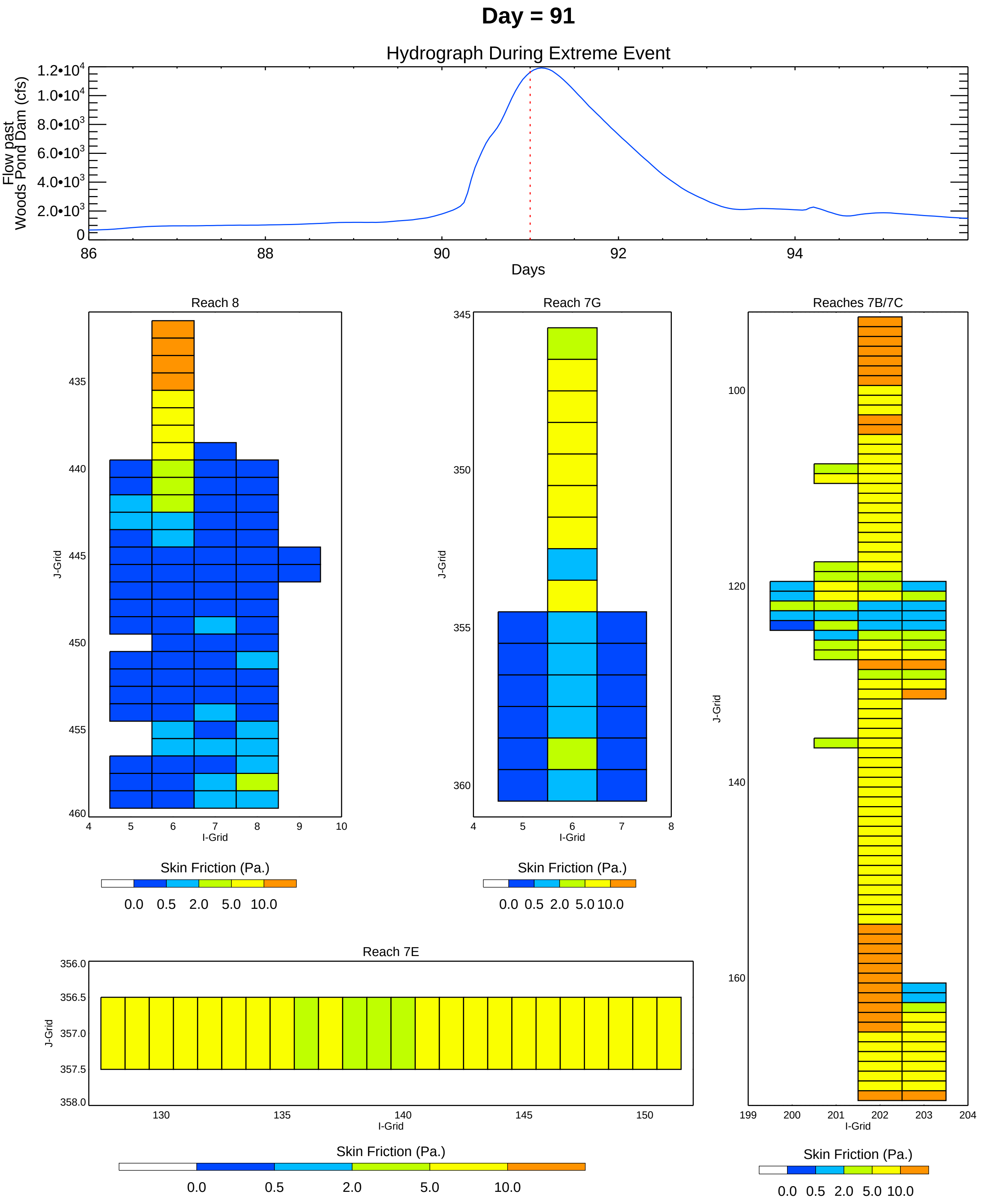

Figure F-1b. Model Calculated Skin Friction During the Extreme Event (Day 91)

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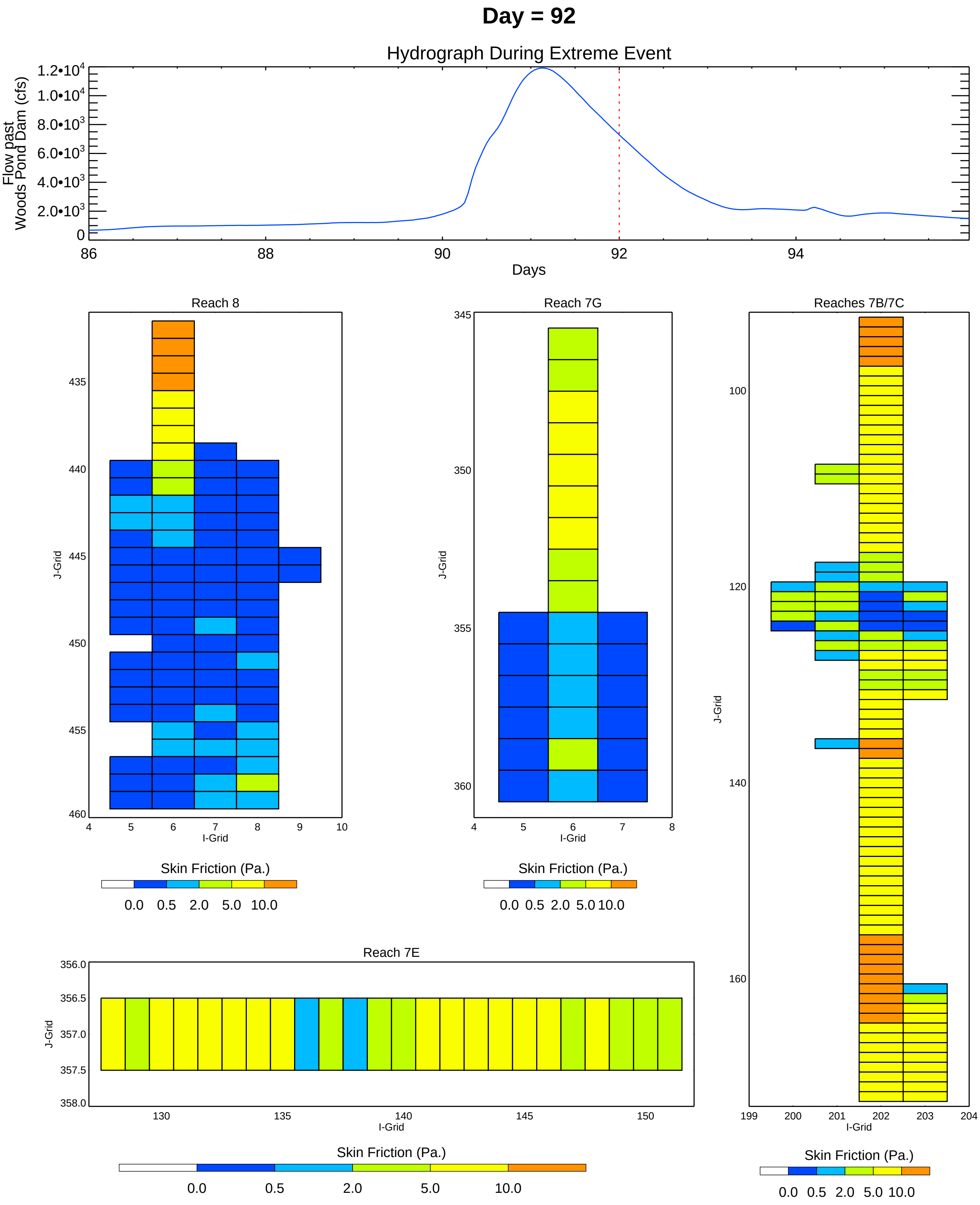

Figure F-1c. Model Calculated Skin Friction During the Extreme Event (Day 92)

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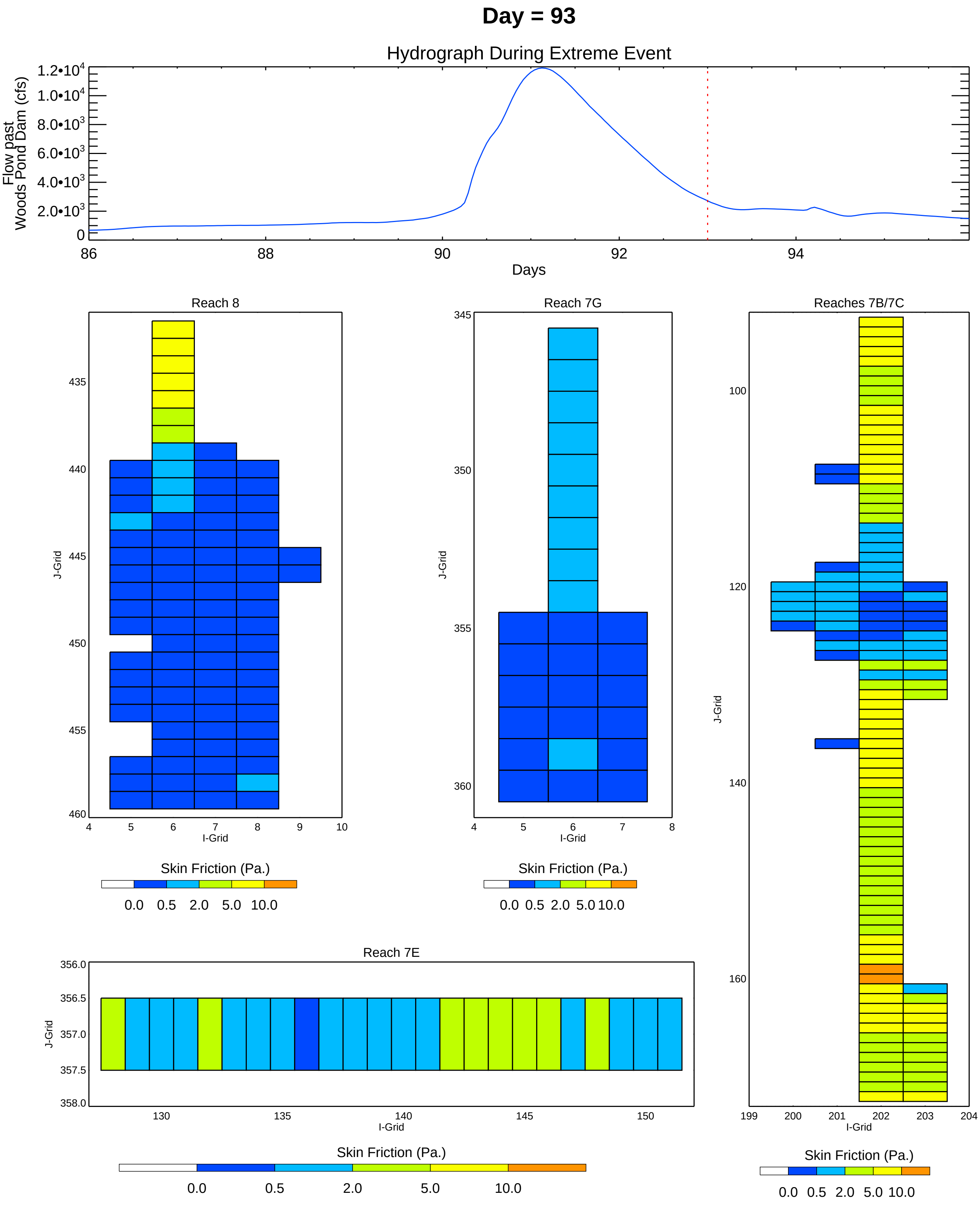

Figure F-1d. Model Calculated Skin Friction During the Extreme Event (Day 93)

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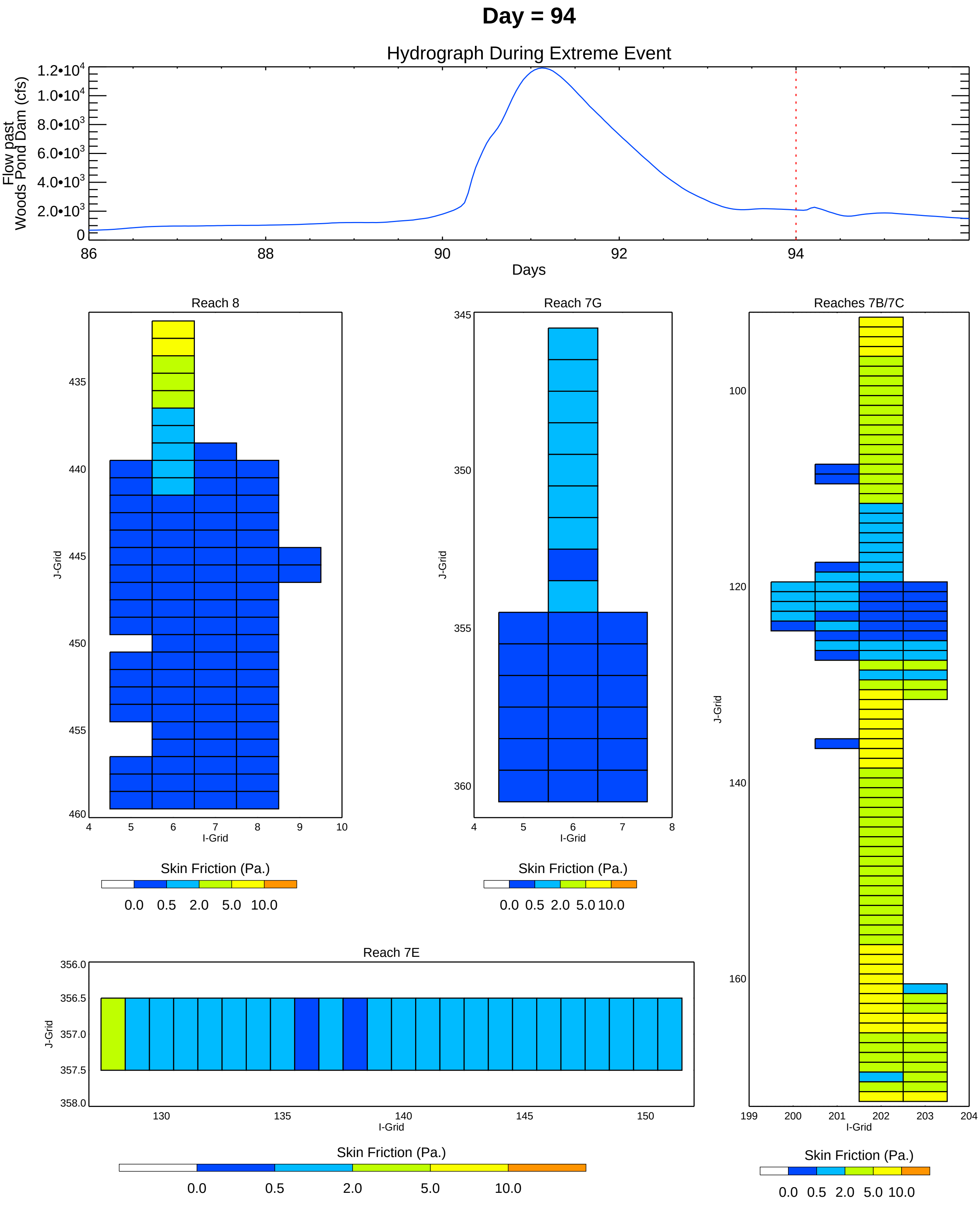

Figure F-1e. Model Calculated Skin Friction During the Extreme Event (Day 94)

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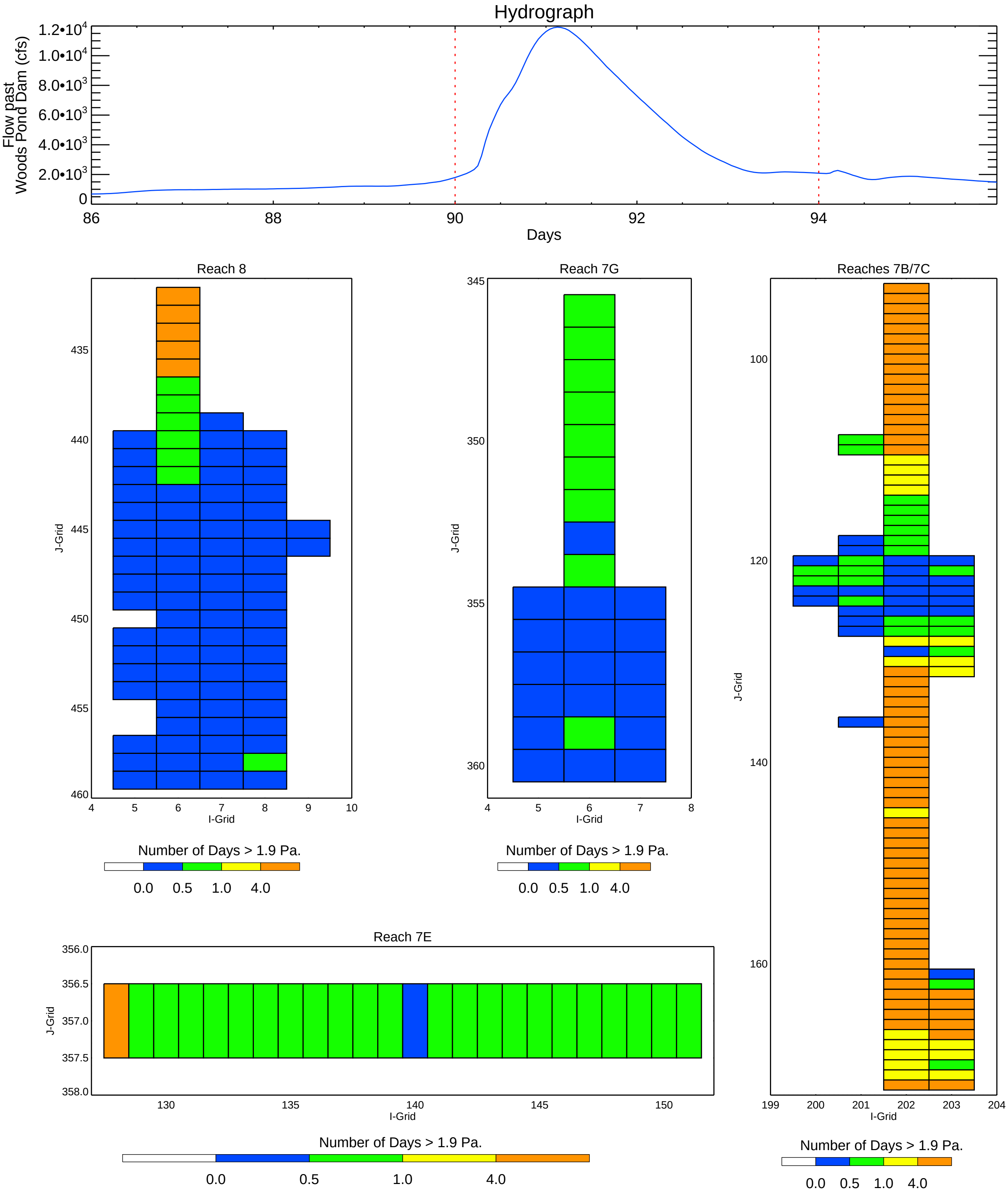
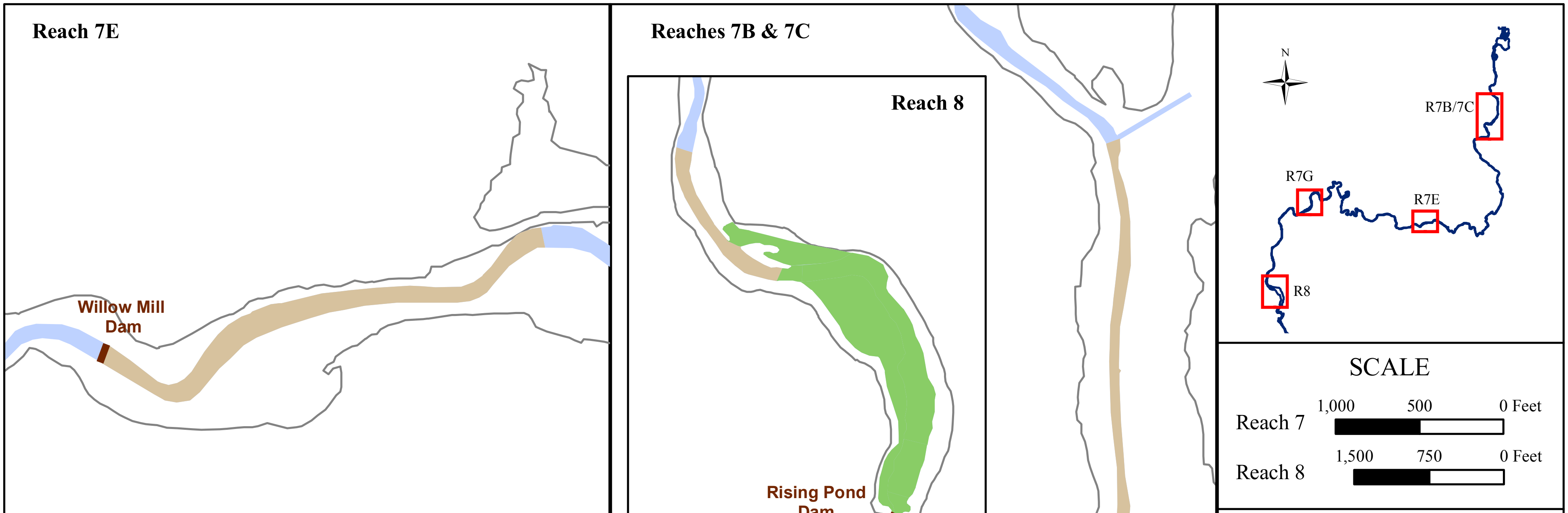


Figure F-2. Frequency of Model Calculated Bed Shear Stress Exceeding 1.9 Pa

Source: Z:\GENcms\MODEL\EPA_EFDC\Results\R78\Proj_R78_SED1CMSBS_0712-28\OUTEXPL\TAUVECH_2030_hourlyOutput.out



SCALE

Reach 7 — 1,000 — 500 — 0 Feet

Reach 8 — 1,500 — 750 — 0 Feet

LEGEND

▬ Major Dams
🟦 Housatonic River
☐ 100-Year Floodplain
Estimated Bed Shear Stress
🟩 Low
🟫 High

Figure F-3
Distribution of bed shear stress in Reaches 7 and 8.

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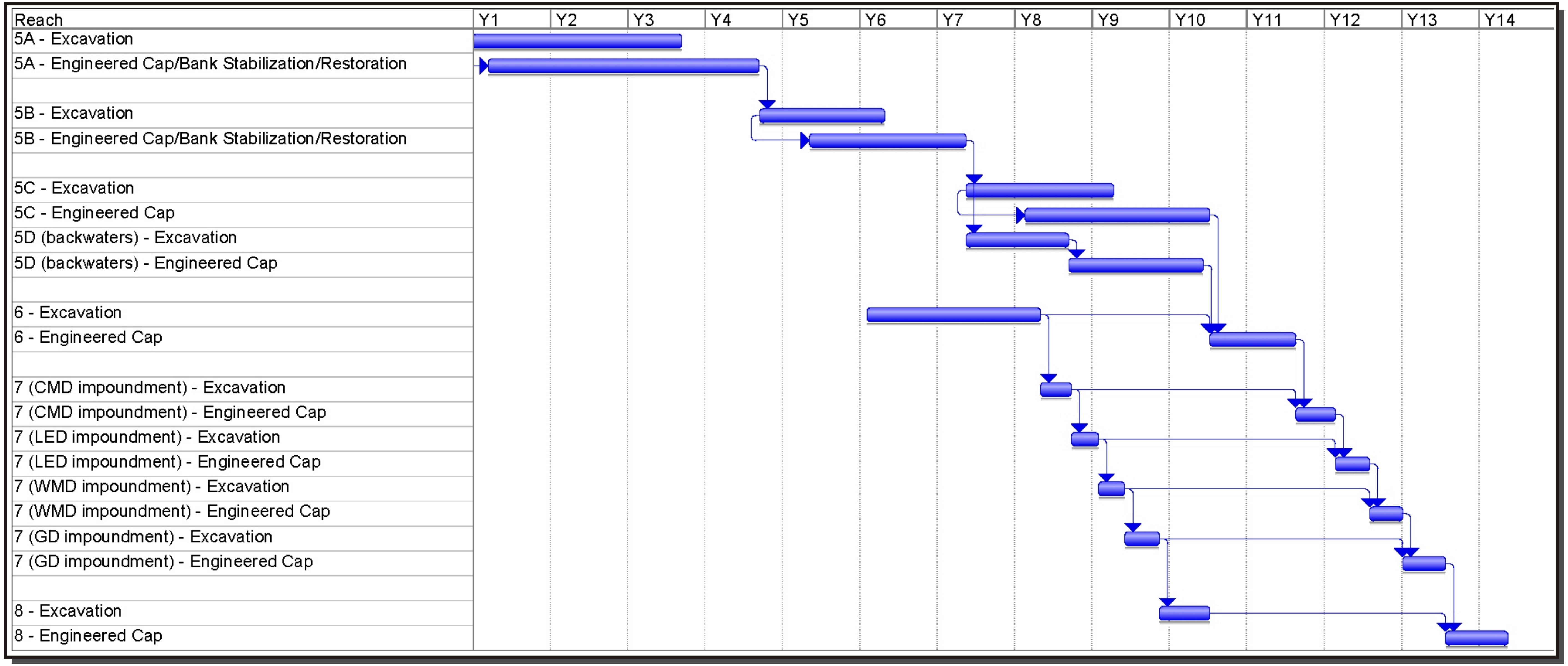

NOTE:

1. CMD = Columbia Mill Dam; LED = Lee/Eagle Dam; WMD = Willow Mill Dam; GD = Glendale Dam.

2. Y = year

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REVISED CMS REPORT

SED 9 CONSTRUCTION SCHEDULE

ARCADIS

FIGURE
F-4

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